The Star Formation History of the WLM Dwarf Irregular Galaxy

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Abstract

We present a wide field-of-view, multi-wavelength imaging data set centered on the WLM dwarf irregular galaxy, as a supplement to the deep, limited-field-size, Hubble Space Telescope observations. WLM is the ideal environment to study isolated-galaxy evolution. WLM is within the Local Group, at a distance of about 3 million light-years, it is protected from tidal interactions from the Milky Way and M31, being outside their dark matter halos. This HI-gas-rich galaxy has been forming stars almost continuously for more than 12 billion years. We explore the spatial distribution, ages, and chemical evolution of its stellar population. We find that the system has been accreting pristine gas (with little chemical enrichment), and may have accreted another dwarf galaxy ~9 billion years ago.

Introduction

This project involves an extensive UV-IR imaging survey of the WLM dIrr Galaxy (also designated, DDO 221; R.A.=$00^h01^m58^s$, Dec.= -15°27'45"), named for its discoverers, Wolf, Lundmark, and Melotte [Melotte 1926]. This system is the most metal-poor galaxy ($Z\sim0.13Z_\odot$) in the Local Group which continues to form stars [Dolphin 2000; Rubio et al. 2015]. When carbon monoxide (CO) was detected with ALMA observations [Rubio et al. 2015], the 10 small molecular cloud cores detected were discovered to be ~25 times smaller than giant molecular clouds in the Milky Way (MW). Within WLM, we can study metal-poor star formation, explore relatively-undisturbed galaxy evolution, and quantify the impact of the cluster-environment on star formation histories of galaxies (tidal interactions, inflow of HI) to compare with simulations [Shen et al. 2014]. This work [Hughes et al. 2019] is the first in a series of papers, first focusing on the evolved population of the galaxy, and testing a general method for distinguishing different generations of stars formed within a system with continuing star formation. The role of internal vs. external feedback in forming stars might be clearer in this galaxy than in the dwarf galaxies within the MW's dark matter halo, with the absence of strong tidal streams.

Observations

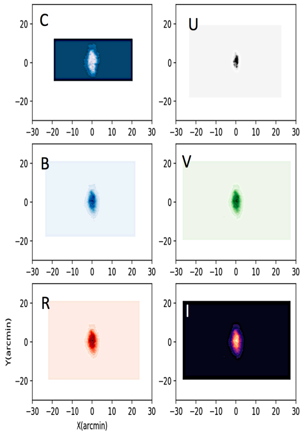


Fig.1: WLM through each filter used.
C (UV and blue), U (UV), B (blue), V (yellow), R (red), I (IR).

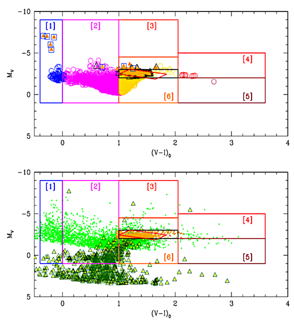
Table 1: Summary of All Images Used

No.	Name	Dates	Telescope	Camera	n_U	n_B	n_V	n_R	n_I	n_O	multiplex
1	wht9409	1994 Sep 29-30	La Palma WHT 2.4m	TEK2	0	0	11	0	14	0	
2	aaj	1994 Nov 08	La Palma INT 2.5m	EEV5	0	0	5	0	3	0	
3	bond4	1999 Jun 12-13	CTIO 0.9m	Tek2K_3	0	2	2	0	2	2	
4	fors9909	1999 Aug 30-Sep 01	Paranal VLT 8m	FORS1	0	4	3	0	0	0	
5	fors0006	2000 Jun 21	Paranal VLT 8m	FORS1	0	3	3	0	3	0	
6	fors0007	2000 Jul 02	Paranal VLT 8m	FORS1	0	4	4	0	0	0	
7	int0207	2002 Jul 14	La Palma INT 2.5m	WFC	1	1	3	2	0	0	x 4
8	cf0209	2002 Sep 29	Maunakea CFHT 3.6m	CFH12K	0	5	0	5	5	0	x 12
9	suba11	2003 Aug 22	Maunakea Subaru 8.2m	SuprimeCam	0	0	4	0	0	0	x 10
10	int0308b	2003 Aug 25	La Palma INT 2.5m	WFC	0	0	3	0	3	0	x 4
11	suba12	2003 Oct 02	Maunakea Subaru 8.2m	SuprimeCam	0	0	0	8	0	0	x 10
12	suba13	2003 Oct 27	Maunakea Subaru 8.2m	SuprimeCam	0	0	0	0	21	0	x 10
13	suba23	2005 Oct 29	Maunakea Subaru 8.2m	SuprimeCam	0	10	12	0	18	0	x 10
14	suba24	2006 Nov 20	Maunakea Subaru 8.2m	SuprimeCam	0	10	12	0	16	0	x 10
15	B0706	2007 Jun 09-10	CTIO 4m	Mosaic2	0	0	0	10	0	0	x 8
16	suba14	2007 Sep 16-17	Maunakea Subaru 8.2m	SuprimeCam	0	0	9	0	59	0	x 10
17	B0909	2009 Sep 12-15	CTIO 4m	Mosaic2	0	0	0	13	34	23	x 7
18	apo2	2010 Oct 09	Apache Point 3.5m	spicam	0	0	0	4	2	3	
19	vimos7	2012 Jul 16-19	Paranal VLT 8m	VIMOS	0	0	15	0	15	0	x 4
20	megawlm	2013 Sep 04-2017 Jan 25	Maunakea CFHT 3.6m	MegaPrime	0	0	0	0	18	4	x 36
21	int1610	2016 Oct 20-21	La Palma INT 2.5m	WFC	0	0	12	0	12	0	x 4
22	int1709	2017 Sep 04	La Palma INT 2.5m	WFC	0	0	0	0	2	0	x 4
23	int1710a	2017 Oct 06	La Palma INT 2.5m	WFC	0	0	0	0	12	0	x 4
24	int1710	2017 Oct 10-11	La Palma INT 2.5m	WFC	0	7	7	0	7	0	x 4
25	apo3	2018 Sep 09	Apache Point 3.5m	arctic	11	1	1	1	0	2	
26	apo5	2018 Oct 10	Apache Point 3.5m	arctic	0	0	0	0	0	21	

Notes:
1. Observers 'FJG', 'GTR', and 'TJB'
2. Observer 'AAJ'
3. Observer H. E. Bond
4. Program IDs 63.L-0342(B) and 63.L-0423(A)
5. Details unavailable
6. Details unavailable
7. Details unavailable
8. Details unavailable
9. Proposal ID o99005, observers Furusawa, Takato, Fuse
10. Observer M. Irwin
11. Proposal ID o02152, observers Kosugi, Komyiyama, Fuse, Sekiguchi
12. Proposal ID o03223, observers Kakazu, Capak
13. Details unavailable
14. Details unavailable
15. Details unavailable
16. Details unavailable
17. Proposal ID 2009B-0337, J. Hughes and R. Leaman
18. Details unavailable
19. Details unavailable
20. Details unavailable
21. Proposal P9/INO1, observers van Loon and Bamber
22. Proposal P4/INO1, observer Javadi
23. Proposal INO1/P4, observer Javadi
24. Proposal '(2016A)C143,' observer M. Monelli
25. Observer: J. Hughes
26. Observer: J. Hughes

Deriving Age and Chemical-Composition

Using all the available images, we used the DAOPHOT/ALLFRAME programs [Stetson 2000; 2005] to identify over 150,000 objects in 2 or more filters. We employed a statistical cleaning method [Mighell et al. 1998] to remove objects belonging to the MW, or objects that were likely to be background galaxies. We determined the distance and mapped the local dust, producing a color (brightness in V-brightness in I) magnitude (absolute brightness in V, corrected for distance and dust) diagram (CMD) for the best ~10,000 stars.



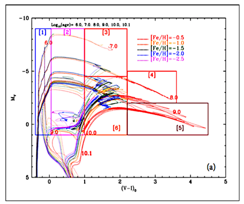
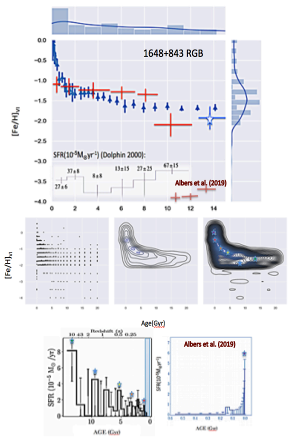


Fig.2: The left-upper panel shows the CMD for our data, the left-lower panel shows the Hubble Space Telescope data for the center of the galaxy and the globular cluster. The right-panel shows the models [Choi et al. 2016] used to obtain age and metal-content for the stars in the black box (red giants).

Results



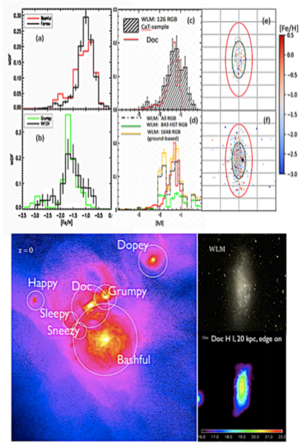


Fig.3: The top panel and center panels are the age-metallicity relationship for WLM red giants, compared with other Hubble data [Dolphin 2000; Albers et al. 2019] showing bursts of star formation.

Fig.4: The histograms show the metallicity distribution functions for model galaxies (The Seven Dwarfs) [Shen et al. 2014] and real Local Group Galaxies (c and d are our data). Panels (e) and (f) are the spatial location of some or our sample. The lower panels are the models, showing that WLM looks like "Doc".

Conclusion

WLM has been forming stars in "bursts", with no long pauses, for over 12 billion years, including accreting pristine hydrogen gas. The evidence suggests that WLM has a bimodal metallicity distribution, and it looks like "Doc" ate "Grumpy" 9 billion years ago. The distance is just under 1 million parsecs.

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